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Effects of Air-Supersaturated Water on Adult Sockeye Salmon (Oncorhynchus nerka)

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Effects of Air-Supersaturated Water on Adult Sockeye Salmon (*Oncorhynchus nerka*)

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Adult sockeye salmon (*Oncorhynchus nerka*) were exposed to air-supersaturated water in the laboratory from July 8 to August 13, 1974, approximately the same time period that they are exposed to supersaturated water during their movement through the lower and middle sections of the Columbia River. The first mortality occurred after 77 h exposure at 120% saturation; 40% of the fish were dead after 127 h. At 115% saturation the first mortality occurred after 523 h (21 days) and 40% were dead after 835 h (35 days). No further mortality occurred at 120 or 115%. However, at 120 and 115% saturation, survivors exhibited many sublethal lesions such as hemorrhaging and emphysema (bubbles) in the mouth, on the gill arches, body surface, and fins, etc. No deaths or signs of gas bubble disease occurred in fish held at 110% saturation in water 2 ft (60 cm) deep. The lethal threshold was near 114% saturation.

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Des saumons nerka (*Oncorhynchus nerka*) adultes ont été exposés à de l'eau sursaturée d'air en laboratoire du 8 juillet au 13 août 1974, soit pendant à peu près la même période où ils sont exposés à de l'eau sursaturée lors de leur passage dans les cours inférieur et moyen du fleuve Columbia. Les premières mortalités se produisirent après exposition de 77 h à une saturation de 120%; 40% des poissons étaient morts après 127 h. A une saturation de 115%, les premières mortalités se produisirent après 523 h (21 jours) et 40% des poissons étaient morts après 835 h (35 jours). Il ne se produisit pas d'autres mortalités à 120 ou à 115%. Cependant, à des saturations de 120 et de 115%, les survivants montrèrent plusieurs lésions sublétales telles qu'hémorragies et emphysème (bulles) dans la bouche, sur les arcs branchiaux, la surface du corps et les nageoires, etc. Il n'y eut pas de mortalités ni de signes de maladie de bulles gazeuses chez des poissons maintenus à une saturation de 110% dans une profondeur d'eau de 2 pi (60 cm). Le seuil létal est dans le voisinage de 114% de saturation.

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ADULT Pacific salmon become afflicted with gas bubble disease (GBD) caused by air-supersaturated water in the Columbia River. The supersaturated water, routinely found up to 130–140% total air saturation, is created by air entrained in the water as it spills over the hydroelectic dams on the river. The severity of the GBD problem has been noted (Rucker 1972; Ebel 1969; Westgard 1964), but it is difficult to document and quantify in the river because of the many other factors affecting fish survival during the upstream spawning run.

In an attempt to determine the impact of GBD, tests were conducted at the Western Fish Toxicology Station (WFTS–EPA), Corvallis, Oreg. There, under controlled conditions, certain variables could be eliminated to isolate gas supersaturation from other stresses found in the Columbia River. Bouck et al. (1976) presented data on acute lethality of gas-supersaturated water to adult sockeye (*Oncorhynchus nerka*), coho (*O. kisutch*), and chinook (*O. tshawytscha*) salmon. This note presents additional information dealing with the longer-term effects of supersaturated water on adult sockeye.

Materials and methods — Adult sockeye were collected from the supersaturated Columbia River at the Bonneville Dam north fish ladder and transported to WFTS in a refrigerated tank truck. They were placed in a holding tank, then randomly selected and transferred to four, circular, 3.6 m diam test tanks that had a water depth of 60 cm and held 6000 liters of water. Ten fish were placed in each tank and held at 13–15 C for 1 wk before the test water was supersaturated. Test facilities and supersaturation generators used are described in Nebeker et al. (1976). Water was supersaturated by injecting compressed air into the water supply system under pressure and then releasing the test water to the tanks under normal atmospheric pressure. The saturation (percent) was controlled by the amount of air injected into the test water.

The fish were tested at total dissolved gas saturation levels of 120, 115, 110, and 100% at 12 C. The test duration was 35 days, spanning the 2–3-wk time period the salmon would be expected to be exposed to gas-supersaturated water in the Columbia River. Water velocity in the circular tanks was maintained at 10–15 cm/s, with a flow rate through the tanks of 40 liters/min. Saturation levels were measured with the Weiss saturometer (Nebeker et al. 1976) using the formula: $\frac{BP + \Delta P - VP}{BP} \times 100 = \%$ saturation, where BP = barometric pressure, ΔP = saturometer reading, and VP = water vapor pressure (Table 1). Chemical analyses of the test water are reported in Samuelson (1976).

Examination of the fish for lesions and signs of gas bubble disease followed the methods outlined by Stroud et al. (1975). Necropsy examinations were conducted on 14 of the 40 test fish to determine cause of death and extent of supersaturation-induced lesions. The threshold concentration (that concentration where significant mortality no longer occurs) was determined using methods similar to those of Sprague (1969).

Results and discussion — Saturation levels of 120 and 115% caused mortality and extensive sublethal signs of GBD in the sockeye; however, fish held at 110% did not appear to differ in behavior or survival from the control salmon at 100% saturation. At 120% saturation, the first fish died after 77 h exposure. The second and third fish died at 100 and 115 h, respectively. At 127 h, the fourth (and last) fish died at 120% saturation (Table 2). Gross lesions of bacterial or fungal infections were not noted during the test in fish held at 120%. Survivors remained near the bottom of the tank, swimming quietly unless disturbed.

TABLE 1. Nominal and measured test levels of total gas supersaturation.

Test tank[a]	Nominal total gas saturation (%)	Measured total gas saturation[b] N	Mean ± *SD*	Range
1	120	63	119.8±0.63	118.1–121.7
2	115	44	115.4±1.45	113.0–119.5
3	110	60	109.5±0.82	106.3–110.7
4	100	—[c]	—[c]	—[c]

[a]6000-liter tank.
[b]Analysis with Weiss saturometer.
[c]Remained near 100% at all times.

TABLE 2. Mortality of adult sockeye salmon (*Oncorhynchus nerka*) tested at 120, 115, 110, and 100% total dissolved gas supersaturation at 12 C.

Nominal % supersaturation[a]	Fish no.	Time to death (*h*)	Sex	Weight (*kg*)	Length (*cm*)
		Tank 1			
120	1	77	F	1.6	52
	2	100	F	1.7	53
	3	115	M	1.8	53
	4	127	M	1.9	54
	5	—[b]	F	1.4	53
	6	—[b]	M	1.7	54
	7	—[b]	M	2.0	57
	8	—[b]	—[c]	1.9	58
	9	—[b]	M	1.6	53
	10	—[b]	—[c]	1.7	54
		Tank 2			
115	1	523	M	2.3	59
	2	667	F	1.7	52
	3	835	—[c]	1.5	54
	4	835	—[c]	1.7	56
	5	—[b]	M	0.5	39
	6	—[b]	—[c]	1.4	53
	7	—[b]	—[c]	1.4	51
	8	—[b]	M	0.8	42
	9	—[b]	—[c]	—[c]	—[c]
	10	—[b]	—[c]	—[c]	—[c]
		Tank 3			
110	1–10	—[b]	No observed GBD		
		Tank 4			
100 (Control)	1–10	—[b]	No observed GBD		

[a]Water depth of 60 cm.
[b]Alive after 30 days.
[c]Not determined.

All fish held at 120% were necropsied at death or at the end of the test to determine cause of death or to characterize the sublethal signs of gas bubble disease that had developed. In the first fish to die, subdermal emphysema (gas blisters) was present in the mouth (Fig. 1), in the dorsal, pectoral, and pelvic fins, and on the margin of the right opercle. The gills appeared congested and swollen, and were covered with excess mucus. When the gill arches were cut, blood and gas bubbled forcefully from the branchial arteries indicating that gas emboli were present under significant pressure in the blood stream flowing to the gills. Gas emboli filled the bulbus arteriosus and ventral aorta, and emboli could be seen in the coronary arteries. Gas emboli were observed in the blood vessels supplying the retina of the eye, and blood, presumably from the rupture of these distended vessels, was present in the left eye.

The second fish to die at 120% (100 h) had bubbles in the scale pockets and on top of individual scales. Gas blisters up to 2 cm diam were observed on the body, and hemorrhages were associated with the gas blisters along the sides of the body (Fig. 2). The pectoral, pelvic, and caudal fins contained gas blisters and hemorrhages, and gas blisters occurred on the inside of the gill covers. The gills were cyanotic and covered with mucus, and blood from cut gill arches contained many gas emboli. Blood vessels in the brain were congested, and gas emboli were observed in the coronary vessels. Emboli were pre-

FIG. 1. Adult sockeye salmon (*Oncorhynchus nerka*) with massive subcutaneous emphysema in the mouth and on the left opercle.

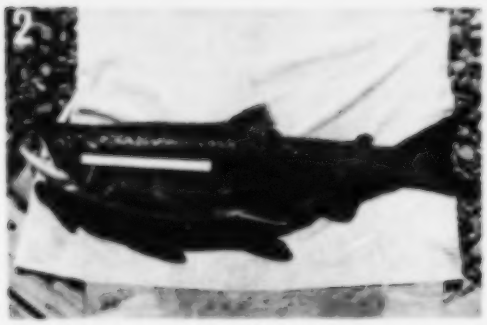

FIG. 2. Adult sockeye with subcutaneous emphysema scattered over the body and fins.

sent in the bulbus arteriosus, the ventricle and auricle, and free gas bubbles were observed in the kidney. Gas blisters were readily apparent under the skin at the base of the gill filaments and on the gill rakers (Fig. 3 and 4).

The third and fourth fish to die at 120% saturation exhibited similar lesions and apparently also died from massive blockage of blood flow in the heart, gills, and other capillary beds of the body. The six fish that did not die exhibited many GBD-caused lesions, but apparently did not suffer from massive emboli formation in the circulatory system sufficient to block blood flow to the gills and cause death.

The fish held at 115% saturation did not begin to die until later in the test; the first death occurred at 523 h. The fish exhibited many external lesions due to gas bubble disease, and bacterial and fungal infections became apparent in tissues devitalized by these lesions. On the first fish to die at 115%, gas blisters were observed on the roof of the mouth, the anal fin, the opercles, and at the bases of the gill arches. Fewer gas blisters occurred on the skin of fish tested at 115% than fish held at 120% saturation. The gills were discolored and the devitalized tissue heavily infected with fungus, giving them a matted yet soupy consistency. No emboli were observed in the heart or associated blood vessels. Gas blisters occurred on the pelvic and pectoral fins of the second fish to die at 115%. Fungal

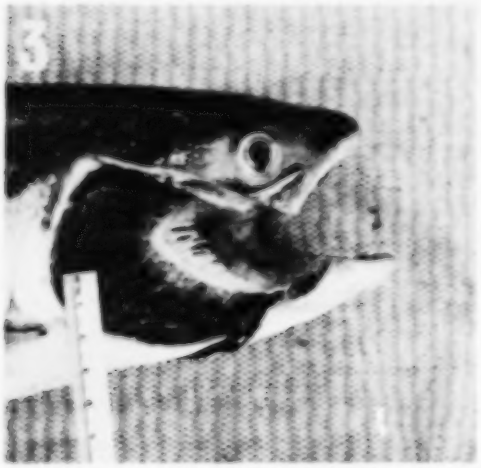

FIG. 3. Cutaway view of the head and gills of adult sockeye showing emphysema on gills, gill arches, and mouth cavity.

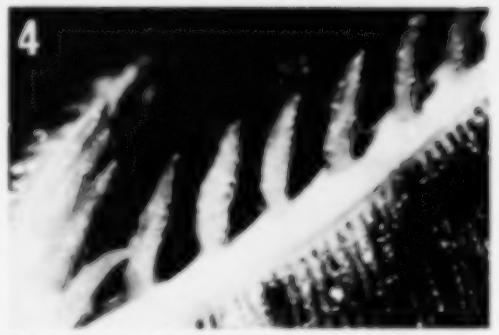

FIG. 4. Gill arch and rakers of adult chinook salmon (*O. tshawytscha*) showing massive subcutaneous emphysema (sockeye and chinook adults had similar gill arch pathology).

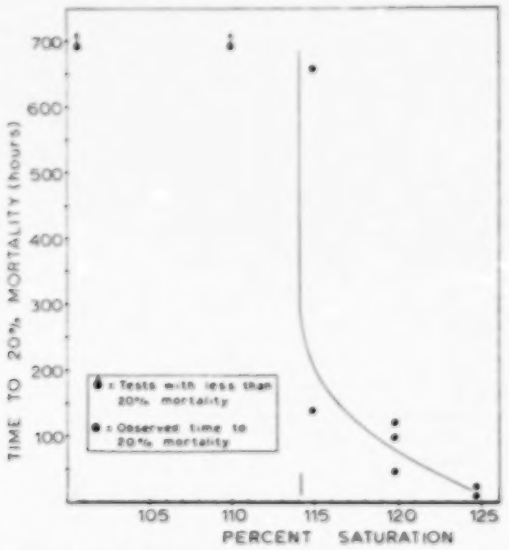

FIG. 5. Threshold concentration determined for adult sockeye (10 fish/test) at 12 C in 60 cm of water.

infections were severe on the body and fins and the right eye had been lost. The third and fourth fish to die at 115% saturation exhibited similar fungal lesions but no external emphysema was observed.

No lesions of gas bubble disease were observed in the fish held at 110% saturation and their behavior was similar to that of control fish.

The lethal threshold concentration (Fig. 5) determined for the adult sockeye at 12 C and 60 cm water depth was near 114%. Data from this study and earlier acute tests (A. V. Nebeker unpublished data) were used, and time to 20% mortality was plotted to obtain the curve. Based on these data, adult sockeye migrating through the Columbia River would probably not be affected by GBD if total gas saturation levels in the river remained below 115%. If the salmon were swimming in deeper water, the 10%/m (of water depth) reductions in total gas saturation due to increased water pressure would provide an additional safety factor.

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